NAL PROPOSAL No. 0033

Correspondent: L. W. Mo
University of Chicago
Research Institute
5640 Ellis Avenue
Chicago, Ill. 60637

Phone: 643-0800 Ext. 8743

PRELIMINARY PROPOSAL TO MEASURE THE HADRONS IN MUON-PROTON INELASTIC SCATTERING AT THE NATIONAL ACCELERATOR LABORATORY

N. E. Booth, L. W. Mo, W. Selove and L. C. Teng

June, 1970

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I. Introduction

Muon-proton inelastic scattering in the energy range attainable only at the National Accelerator Laboratory is expected to reveal exciting information about the fundamental structure of nucleons. Among many interesting possibilities, one can study the following subjects:

(1) μp elastic scattering by measuring the scattered muons only,

(2) μp inelastic scattering by measuring the scattered muons only,

(3) Total photo-absorption cross section of the proton by extrapolation to the limit of $q^2 \rightarrow 0$,

(4) μp inelastic scattering by measuring the scattered muons and all the hadrons produced.

It is the last subject in which we are particularly interested and which we are planning to do at the National Accelerator Laboratory. So far as we know, no one has attempted to measure all the final-state hadrons, with a multiple-particle detection system, in either ep or μp inelastic scattering processes. However, the present Fermi Institute - Pennsylvania collaboration has proposed such an experiment at the 10 GeV Wilson Electron Synchrotron at Cornell University. A 200-hour preliminary run has been scheduled for the period of June to July of 1970. If everything goes well, we hope that the main data-taking can be started by November, 1970. This Cornell experiment will give us valuable experience for the high energy muon-proton inelastic scattering experiment at the National Accelerator Laboratory. By the time the NAL muon beam becomes operative we hope to have already learned a great deal about this difficult and interesting experiment, on aspects in physics as well as in equipment. Interesting questions, such as the multiplicity of hadrons in the deep inelastic region and at large momentum transfers, could have been answered to some extent. As we have planned to use a large system of proportional wire chambers (5 concentric half cylinders, $\sim$8,000 wires) to measure the hadrons, such experience would put us in a technological lead for doing multiple-particle production experiments in general.

In addition, the detection system suggested in this proposal can serve as a general purpose facility of the National Accelerator Laboratory. The large dipole magnet, together with the hybrid wire chamber system (proportional and FET [field-emission transistor readout]) can be used to measure multiple-particle productions of any kind, such as the inelastic scattering processes: pp, $\pi^{\pm}$p, $K^{\pm}$p, etc.

In the following sections, we will first briefly review the current experimental and theoretical situation of deep inelastic ep and μp scattering. A short description of the ep scattering experiment, at Cornell University, will follow since the hadron detection system for the proposed NAL experiment is similar. Then the experimental plan at the National Accelerator Laboratory will be fully described.

II. *Review of the Current Status of ep Inelastic Scattering*

During the past three years, electron-proton inelastic scattering has been studied in great detail at SLAC by a SLAC-MIT collaboration.[1] In these experiments, only the scattered electrons were detected. The interesting features of the results are summarized as follows:[1, 2]

A. The q^2-dependences for the electro-excitation of the 1.238-, 1.512-, 1.688-, and 1.920-GeV nucleon isobars are rather similar. Their electromagnetic form factors decrease slightly faster than that of the elastic peak with increasing values of q^2. This behavior agrees with the predictions given by Walecka et al.[3]

B. As q^2 increases, the electro-excitation of the nucleon isobars becomes totally unimportant. The cross section is dominated by the non-resonant part. As shown in Figures 1 through 3, the differential cross section $\frac{d^2\sigma}{d\Omega dE'}$, measured at various fixed incident energies and scattering angles, rises roughly exponentially as a function of the missing mass W. In the deep inelastic region (i.e., when the missing mass W is greater than 2 GeV), the electromagnetic form factor shows a q^{-2}, rather than a q^{-4}, dependence which is rather surprising and of considerable current interest.

These results have been compared, in only an approximate way, with the scale invariance model of Bjorken,(4) and the vector dominance model of Sakurai.(5) The situation can be summarized as follows:

A. Scale Invariance -

Using only the small angle data (6° and 10°), and assuming $\sigma_L/\sigma_T = 0$ (where σ_L is the longitudinal cross section; and σ_T the transverse cross section), the product νw_2 (where ν is the energy transfer to the target, w_2 is one of the two form factors) exhibits to within $\sim$30% a universal feature as a function of the salar variable $2M_p\,\nu/q^2$. As the value of $2M_p\,\nu/q^2$ increases, the product νw_2 becomes slightly smaller.

If we use the same assumption $\sigma_L/\sigma_T = 0$, the universal curve for the 18° data shows a much faster decreasing trend as compared to the smaller angle data.(2)

B. Vector Dominance -

If the mass of the vector meson in Sakurai's model is made variable, then the differential cross section $\frac{d^2\sigma}{d\Omega dE'}$ can be completely described by his theory.

As q^2 increases, the value of the vector meson mass varies from the ρ mass to ~ 1.4 GeV.[2] However, the prediction of the ratio σ_L/σ_T appears to be too large as compared to the few experimental values. The experimental situation is $0 < \sigma_L/\sigma_T \lesssim 0.5$.

There has been a tremendous amount of theoretical effort attempting to explain these experimental data. Theories appear in the literature at the rate of approximately two papers per week. Many of these theoretical conjectures are in contradiction with each other, yet the authors always claim their individual success. For example, numerous versions of the so-called Parton model are claimed to give the basic reasons for the scale invariance;[6] yet phenomenological analysis of the experimental data indicates that scale invariance is neither proved nor disproved.[7] Also, there are conjectures against the "point scattering" picture which are based on the argument that the longitudinal distance between the emission and the absorption points of the space-like photon in virtual Compton scattering can be proven to be very large.[8,9]

These arguments cannot be settled just by examining the SLAC-MIT data, because they are only the total cross sections of the virtual photons. However, these theoretical arguments can be settled (or more constructively, we will understand more about the fundamental physics) if the final states of the hadrons can be measured. The first measurements necessary appear to be

a. the multiplicity of the hadrons, and

b. the momentum distribution of each hadron.

Very recently Feynman[10] proposed that in high energy collisions the momentum distribution of the hadrons in the final state should follow a dx/x distribution law, where x is the ratio of the longitudinal momentum to the total center-of-mass energy. Yang and collaborators[11] suggested the hypothesis of limiting fragmentation which asserts that, in hadron collisions, the projectile and the target fragment separately, and the number of fragments approaches a limiting probability distribution as the energy increases. These ideas could be tested in either ep or μp inelastic scattering experiments. These are cleaner than the corresponding πp or pp collision experiments because only the target hadron can fragment.

Based on these reasons, we feel that there is more than enough incentive to do the ep scattering experiment at Cornell University; and later, to do the high energy μp scattering experiment at the National Accelerator Laboratory.

III. The Cornell ep Scattering Experiment

We plan to do the electron-proton inelastic scattering experiment at the 10 GeV Cornell Electron Accelerator by the fall of 1970. In this experiment, the final state hadrons as well as the scattered electrons will be detected. It should be noticed that such an experiment cannot easily be performed at SLAC because of the short duty cycle. At Cornell University the Wilson Accelerator operates at 60 pps and the beam spill is $\sim$1 msec/pulse. The experimental arrangement is shown schematically in Figure 4. A 5-cm long liquid hydrogen target is placed inside a bending magnet, built by Professor V. Telegdi at the University of Chicago, which has a poleface area of 4' x 4', and a gap of 2'. The target will be surrounded by proportional chambers of half-cylinder shape. Since the proportional wire chambers work continuously, the signals from each wire must be electronically delayed and will be read into the on-line computer only when the trigger gate, defined by a scattered electron, occurs. Downstream from the magnet there will be a threshold gas Čerenkov counter, dE/dx counters, and shower counters to define the inelastically scattered electrons. As shown in Figure 4, the scattered electrons as well as the hadrons which come out of the bending magnet will be detected both inside and outside the magnet by the chamber system. The accuracy of momentum measurement for this proposed system is estimated to be better than 150 MeV/c, assuming a magnetic field of 15 kG and a spatial resolution of 1-mm for the proportional wire chambers, and 0.5-mm for the FET chambers. This accuracy will certainly remedy the fact, to a great extent, that we do not have a π^o detector.

The region of exploration is shown schematically in Figure 5. With a 10 GeV electron beam we can approximately cover the region of missing mass from 2 to 4 GeV, and q^2 from 2 to 5 $(GeV/c)^2$.

We are forced to use the more expensive proportional wire chamber because a limit on the event rate is imposed by the memory time of the wire chambers; the most serious background is produced by the low energy knock-on electrons due to e-e scattering. Since the target is inside the magnetic field, the hadron tracks we are looking for would be buried in a tremendous number of low energy electron tracks if ordinary wire chambers were used. Consider the following conditions we have in mind for the Cornell experiment:

N_e = 10^6 electrons/pulse (60 pulses/sec, 1 msec beam spill/pulse)

N_p = 2.1×10^{23} protons/cm^2 (5-cm long liquid hydrogen target)

τ = 100 nsec resolving time of the proportional chamber).

The number of knock-on electrons with energy > 10 MeV will be ~ 1 per 100 nsec. If instead, we use the ordinary wire chamber with a sensitive time of ~ 1 to 2 μsec, the situation would be disastrous.

The proportional wire chambers to be used in the ep inelastic scattering experiment have a very unique design, as developed by T. Nunamaker and M. Neumann(12) at the Enrico Fermi Institute. It is shown schematically in Figure 6. The anode wires are made of 25 μ stainless steel, and spaced 1-mm apart. They are strung along the axial direction of the half cylinder, and supported by the frame of the chamber. The cathode on the downstream side of the beam direction consists of a 2-mil thick Tedlar foil with thin aluminum strips printed on both sides. This Tedlar foil serves as the support for the circular wires, and also as the gas seal. When a minimum ionizing particle passes through the chamber, these aluminum strips will sense signals of positive polarity induced by the avalanche electrons collected by the anode wire. This ingenious method allows us to have two or more coordinate signals from a single chamber, as compared to only one for a conventional Charpak chamber. The gas used in the chamber is a mixture of $\approx$80% argon and $\approx$ 20% isobutane.

We have compared the performance of the amplifiers[(13)] currently being used at different laboratories. They are all voltage amplifiers. As the chamber size becomes larger, the larger capacitance will reduce the signal amplitude and this may lead to unusual difficulties. We have built an improved version of an amplifier, originally designed by L. Koester,[(13)] with the discriminator threshold reduced from 1 mv to 0.15 mv. At this low discrimination level, shielding of the noise becomes a problem. The final system which we plan to use employs a charge-sensitive amplifier developed by T. Nunamaker.[(14)] As the output is proportional only to the input charge, it has the advantage of low cross-talk, and of being insensitive to the magnitude of the wire capacitance. The threshold of the discriminator is $\approx 5 \times 10^{-15}$ Coulomb and this is more than adequate for a gas amplification of the order of 10^6. A schematic diagram of the system, which includes the amplifier, discriminator, electronic delay, coincidence gate, and shift registers, is shown in Figure 7. We are planning to have the whole system miniaturized.

The wires on the two sensing planes of each chamber will make an angle of 30°. The total number of events is expected to be of the order of 40,000. Pattern recognition for the measured tracks will be done by an on-line technique with the help of a CRT display, light-pen instruction, and human operators. This is not a difficult job for the people from the University of Pennsylvania as they own an HPD machine for automatic measurement of bubble chamber pictures. Radiative corrections for this experiment can be carried out by modifying the work[15] done for the SLAC electron scattering experiment.

IV. Experimental Plan on μ p Inelastic Scattering at the National Accelerator Laboratory

Because of the limitation in energy of the primary electron beam currently available at Cornell University (10 GeV) and SLAC (20 GeV), the maximum missing mass of the scattered electrons can be explored only up to 4 and 6 GeV respectively. At the National Accelerator Laboratory, this upper limit can be extended to 13 GeV for a muon beam of energy 100 GeV, and 19 GeV, for a muon beam of energy 200 GeV. As shown in Figures 8 and 9, measurements can be made at values of q^2 up to ≈ 30 $(\mathrm{GeV}/c)^2$.

A. Arrangement of Experimental Apparatus -

Apart from the trigger counters and the difference in size, the experimental setup for the μ p inelastic scattering experiment, to be proposed at the National Accelerator Laboratory, is quite similar to that for the ep inelastic scattering experiment proposed at Cornell University. Because the energy is much higher at the National Accelerator Laboratory, we have to use a much longer magnet in order to measure the momenta to the required accuracy. Detection of gamma rays from the decay of neutral pions becomes absolutely essential as one naturally suspects that the multiplicity of hadrons will increase rapidly at higher energies.

We plan to place a 1-meter long liquid hydrogen target inside a large bending magnet. This bending magnet is assumed to have a useful volume of 2m (gap) x 3m (width) x 6m (length), and a field strength of 20 kG. As shown in Figure 10b, the liquid hydrogen target is subdivided into four segments and they are surrounded by proportional wire chambers of the shape indicated in the diagram. These wire chambers are assumed to be 1.5 meters high. The liquid hydrogen target can be made a few inches in diameter. The chambers are capable of covering all of the forward hemisphere, except for the small space left open at the top and bottom.

The remainder of the volume of the magnet will be filled with FET chambers of size 2.5m x 1.5m. Appropriate areas of each of these chambers will be de-sensitized where the primary muon beam goes through. After the bending magnet, there is a drift space of length 15 meters. In this drift space two more sets of FET chambers will be installed to measure the scattered muons as well as the hadrons coming out of the bending magnet. A 5-meter thick iron filter ($\approx$40 collision lengths) is installed at the end of the drift space to stop the strongly interacting particles. After the iron filter, a plastic scintillation counter of size 4.5 ft (horizontal) x 9 ft (vertical) will set the trigger signal for the scattered muons. This trigger counter will be arranged in the form of a hodoscope, with 5 x 9 elements, and will accept muons scattered in the angular range of 1° to 4°. A similar arrangement will also be made on the other side of the primary beam in order to increase the event rate.

B. π^0 Detector -

The wire separation for the proportional wire chambers is $\approx$1-mm; and for the FET chambers, 0.5-mm in the beam-bending direction, and 1-mm in the non-bending direction. The energy resolution of our designed system is estimated to be not much better than $\approx$400 MeV for a muon beam of energy 100 GeV. Therefore, it is very desirable to have a π^o detector. This choice can be accomplished by surrounding the target, at a distance of 1 meter, with 1.8-cm lead plates ($\approx$3 radiation lengths), followed by two more layers of FET wire chambers to measure the directions of the converted gamma rays. This will reduce the fitting of the event by one constraint so that we could detect three π^o's and still have a 1 c fit.

C. Muon Beam and Its Monitoring -

As the quality of the NAL muon beam is still unknown, we assume that its energy resolution can be as good as 5%, and the beam size can be smaller than a few inches in diameter. The beam intensity is assumed to be approximately 10^7 per one-second long beam spill. Under these reasonable assumed conditions, the incoming energy, position, and incident angle of each beam particle can be experimentally determined by placing 2 sets of small flat proportional wire chambers in front of the last bending magnet of the beam transport system, and 2 more sets just after the bending magnet and before the liquid hydrogen target.

We would like to use the high intensity muon beam in Area 1. In the event that the construction of that beam is delayed, the alternative is to use the 3.5 milli-radian high intensity pion beam in Area 2. By placing a 2-meter long iron filter at the position of the first energy slit of that beam line, it should be possible to generate $\approx 10^7$ μ's/pulse from a pion beam of intensity $\approx 10^9$ π's/pulse.

D. Expected Counting Rate -

In the standard notation, the differential cross section for μp (same as for ep) scattering can be written as

$$\frac{d^2\sigma}{d\Omega dE'} = \frac{\alpha^2 \cos^2\frac{\theta}{2}}{4E_o^2 \sin^4\frac{\theta}{2}} \left[W_2 + 2W_1 \tan^2\frac{\theta}{2}\right]$$

where E_o, E' = incident, scattered muon energy,

θ = scattering angle,

α = fine structure constant = 1/137,

W_1, W_2 = two form factors.

Since we are only interested in small values of θ (1° to 4°), to first order, the contribution of the W_1 term can be neglected. Then the cross section can be written as

$$\frac{d^2\sigma}{d\Omega dE'} \approx \frac{\alpha^2 \cos^2\frac{\theta}{2}}{4E_o^2 \sin^4\frac{\theta}{2}} \frac{(\nu W_2)}{\nu}$$

where $\nu \equiv E_o - E'$.

Further approximations can be made by substituting the actual value of νW_2, as obtained from the SLAC ep scattering data(1) with the assumption that $\sigma_L/\sigma_T = 0$. We assume the following parameters:

$N\mu$ = 10^7 μ/pulse (1-sec long beam spill, 1 pulse every 4 sec),

N_p = 4.2×10^{24} protons/cm^2 (1-meter long liquid hydrogen target),

$\Delta\Omega$ = 0.006 sr (as defined by the designed trigger hodoscope. This number should be doubled if two trigger counters are used, one on each side of the primary beam),

$\Delta E'$ = 20 GeV (corresponding to $\Delta W \sim 2$ GeV).

Some contours of constant rate are shown in Figures 8 and 9. It is interesting to see that the trigger rate is always better than 60/hour, and it stays essentially unchanged if the primary muon energy is 200, instead of 100 GeV. This will permit measurements to be made at values of missing mass W = 6 to 13 GeV with a 100 GeV muon beam, and W = 13 to 19 GeV with a 200 GeV muon beam. Values of q^2 can be explored in the range of 5 to 30 $(\mathrm{GeV}/c)^2$.

E. Background -

After careful consideration it appears that the most serious background for this μp scattering experiment is the low energy knock-on electrons from μ - e scattering. The same is true for the proposed ep scattering experiment at Cornell University. The cross section for μe (same for ee) scattering is given by [16]

$$\frac{d\sigma}{d\nu} = 2\pi r_e^2 \frac{m_e}{\nu^2}$$

where $r_e = 2.82 \times 10^{-13}$ cm (classical radius of electron),

m_e = rest mass of electron.

The integrated cross section is given by

$$\sigma = \int_{E_{cut-off}}^{\infty} \frac{d\sigma}{d\nu} \, d\nu = 2\pi r_e^2 \frac{m_e}{E_{cut-off}}$$

The total rate of knock-on electrons during the 1 sec beam-on time as a function of cyclotron radius corresponding to $E_{cut-off}$ and 20 kG is plotted in Figure 11. It can be seen that the rate is tolerable for both the proportional and FET chambers as arranged.

Other possible backgrounds, such as wide angle bremsstrahlung,[15] pair-production, etc., are too small to be considered.

F. Data Analysis -

Data analysis for this proposed μp scattering experiment consists mainly of (1) kinematics reconstruction, and (2) radiative corrections. Since the experiment is essentially identical to the ep scattering experiment proposed at Cornell University, the programs for data-analysis will be very similar. By the time this proposed experiment could start, most of the problems will already be solved. We will repeat here, briefly, some of the crucial points:-

(1) Pattern Recognition and Kinematics Reconstruction

For 1,000 hours of data-taking time, the total number of muon scattering events should be about 70,000. For this number it is not essential to rely on fully-automated machinery to do the analysis.

As mentioned before, our chambers provide two stereo views, at an angle of 30°, for all the visible charged tracks. If these two stereo views are displayed on the same CRT scope it will be easy for a human operator to tell which two trace views belong to one track by their physical proximity. Then the operator can use a light-pen interrupt to instruct the computer how to do the pattern recognition. After that, kinematics reconstruction becomes relatively easy.

(2) Radiative Corrections

The method and program for ep (μp) scattering experiments, in which only the scattered electrons (muons) are detected, are already fully developed.[15] For this proposed experiment some minor modifications on the method and program will be made during the next 12 months.

V. Cost Estimate of the Equipment

The major part of the equipment cost comes from the large volume bending magnet and the wire chambers. The break-down is as follows:

A. Magnet

A large bending magnet, of size 2m (gap) x 3m (width) x 6m (length), is shown in Figure 12. For reasons of economy, the coils should be made with aluminum conductors. The characteristics and cost of the magnet are given below:-

Field strength = 20 kG (maximum),

Ampere-turns = 3.18×10^6,

Power = 6.5 mega-watts,

Weight of iron = 1,720 tons,

Cost of iron = \$1.38 M (\$0.4/lb),

Weight of Aluminum = 60 tons,

Cost of Aluminum = \$0.12 M (\$1.0/lb),

Cost of Power Supply = \$0.20 M (\$30/kw),

Total Cost = \$1.7 M.

Cost of power to run the magnet for 1,000 hours = \$58,000 (0.9 cents/kw-hr).

As this magnet is a picture-frame magnet is can easily be shimmed to give a uniformity much better than we really need $\left(\text{i.e. } \frac{\Delta B}{B} \approx 10^{-4}\right)$.

We have investigated using super conducting coils. It appears that there is no economic advantage in so far as the construction costs are concerned. Since the cost of power to operate the aluminum coils is relatively minor, we consider it advisable to stick to the simpler and more reliable conventional magnet. This magnet will make an ideal general purpose facility for NAL. We suggest that the National Accelerator Laboratory provide funds for it.

B. Wire Chambers

An approximate inventory indicates that the situation for wire chambers is as follows:

No. of proportional wires = 15,000,

No. of FET wires = 85,000,

Cost of proportional wires = \$180,000 (including mechanical shop, \$12/wire),

Cost of FET wires = \$220,000 (including mechanical shop, \$2.5/wire),

Total Cost = \$400,000.

By the time the proposed ep scattering experiment at Cornell University is finished, we will free electronics for the proportional and FET chambers which are worth almost \$100,000. We still need the capital for equipment in the amount of \$300,000 to finish the job. As far as we can see, the equipment should belong to the National Accelerator Laboratory as a general facility. Therefore, we hope that the National Accelerator Laboratory will provide the funds for it. The electronics and the techniques for constructing both the proportional and the FET wire chambers have been fully developed by T. Nunamaker, et al., at the Enrico Fermi Institute. We will be glad to assume the responsibility of building the large magnet and the wire chambers for the National Accelerator Laboratory. After that, not only our group would use these facilities to do the proposed μp scattering experiment, but hopefully other potential users could benefit from the facilities.

C. Electronics and Hodoscopes

These items, together with other miscellaneous things, will cost relatively little. A total sum of $50,000 should be more than sufficient.

D. On-line Computer

Because of the size of the experiment under consideration, we need an on-line computer of reasonably large capacity to do data logging, on-line display monitoring and some data reduction. The PDP-8 system with only 4 K memory, to be used at the Cornell experiment, is too small. Any 16 to 24-bit XDS or DEC computer of 16 K memory, equipped with tape drive, line printer, card reader, and some scope display, would be adequate. The cost of such a system is about $100,000. We hope that the National Accelerator Laboratory can provide an on-line computing facility by the time the muon beam becomes operative.

VI. Facilities of this Collaboration

We will have the support of the elite electronics shop of the Enrico Fermi Institute. This shop, under the direction of T. Nunamaker, is well-known for their pioneer work in various types of wire chambers and development of electronics. All the proportional and FET wire chambers will be built by them. Also, we anticipate having the support of the engineering group of Pennsylvania. Most important, this group owns an HPD machine plus a number of operators for it. Data reduction should not be difficult.

This group can also have access to IBM 360/65 computer at the University of Pennsylvania at very little cost. This will considerably reduce the cost for data analysis.

VII. Proposal and Request to the National Accelerator Laboratory .

We propose to measure the hadrons produced in μp inelastic scattering, with the detection configuration as described above, at the National Accelerator Laboratory. We are interested in muon beams of energy 100 GeV to 200 GeV, with an energy resolution of a few percent. The beam intensity will be 10^7 μ's per 1-sec beam spill. If it is possible, we can use a factor of 5 more.

Initially, we request 200 hours of beam time to make testing runs. After a period of 3 months we request a block of data-taking time of 600 hours. Assuming this is successful we may request an extension of an additional 400 hours of data-taking time.

We also request that the National Accelerator Laboratory provide us with the following equipment:

(1) The large volume bending magnet as above mentioned. The cost of this magnet is beyond our means;

(2) The liquid hydrogen target. We need a 1-meter long liquid hydrogen target, divided into 4 segments. The diameter should be compatible with the yet unknown muon beam size;

(3) On-line computing facilities; and,

(4) Iron for the muon filter.

This collaboration will take the full responsibility for the construction of all the proportional and FET wire chambers, and also the magnet and the hodoscopes. As for the financing of the whole system, we would be happy to agree on any mutually satisfactory plan with the National Accelerator Laboratory. As we repeatedly mentioned before, the whole system can be used to do other interesting types of inelastic scattering experiments, such as in pp, $\pi^{\pm}p$, and $K^{\pm}p$ collisions. It is our sincere wish that this detection system can be built and be used as a general purpose facility of the National Accelerator Laboratory.

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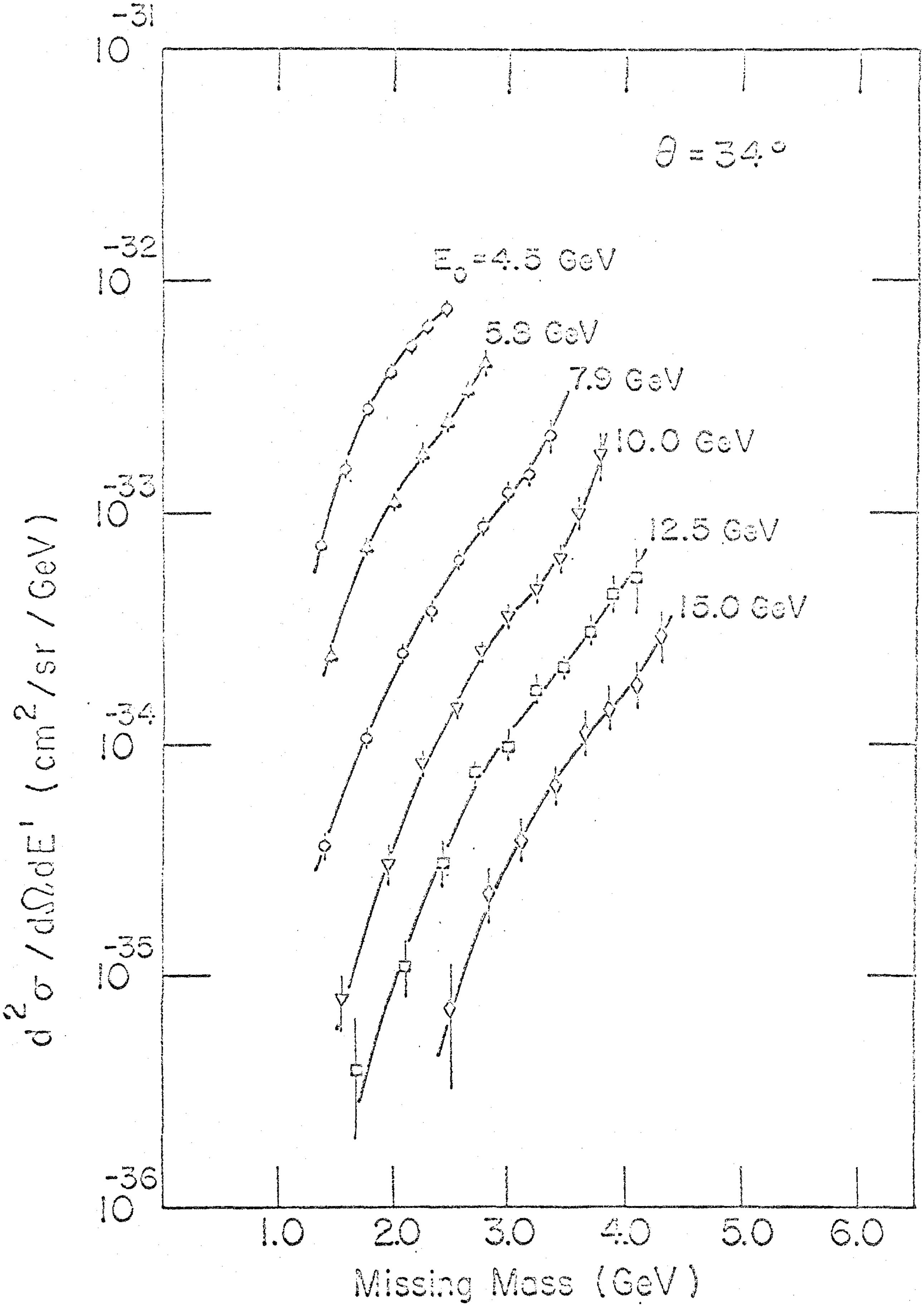


10^{-31}
10^{-32}
10^{-33}
10^{-34}
10^{-35}
10^{-36}
$\theta = 34°$
$E_0 = 4.5$ GeV
5.8 GeV
7.9 GeV
10.0 GeV
12.5 GeV
15.0 GeV
$d^2\sigma / d\Omega dE'$ (cm^2/sr / GeV)
1.0
2.0
3.0
4.0
5.0
6.0
Missing Mass (GeV)

Fig. 1

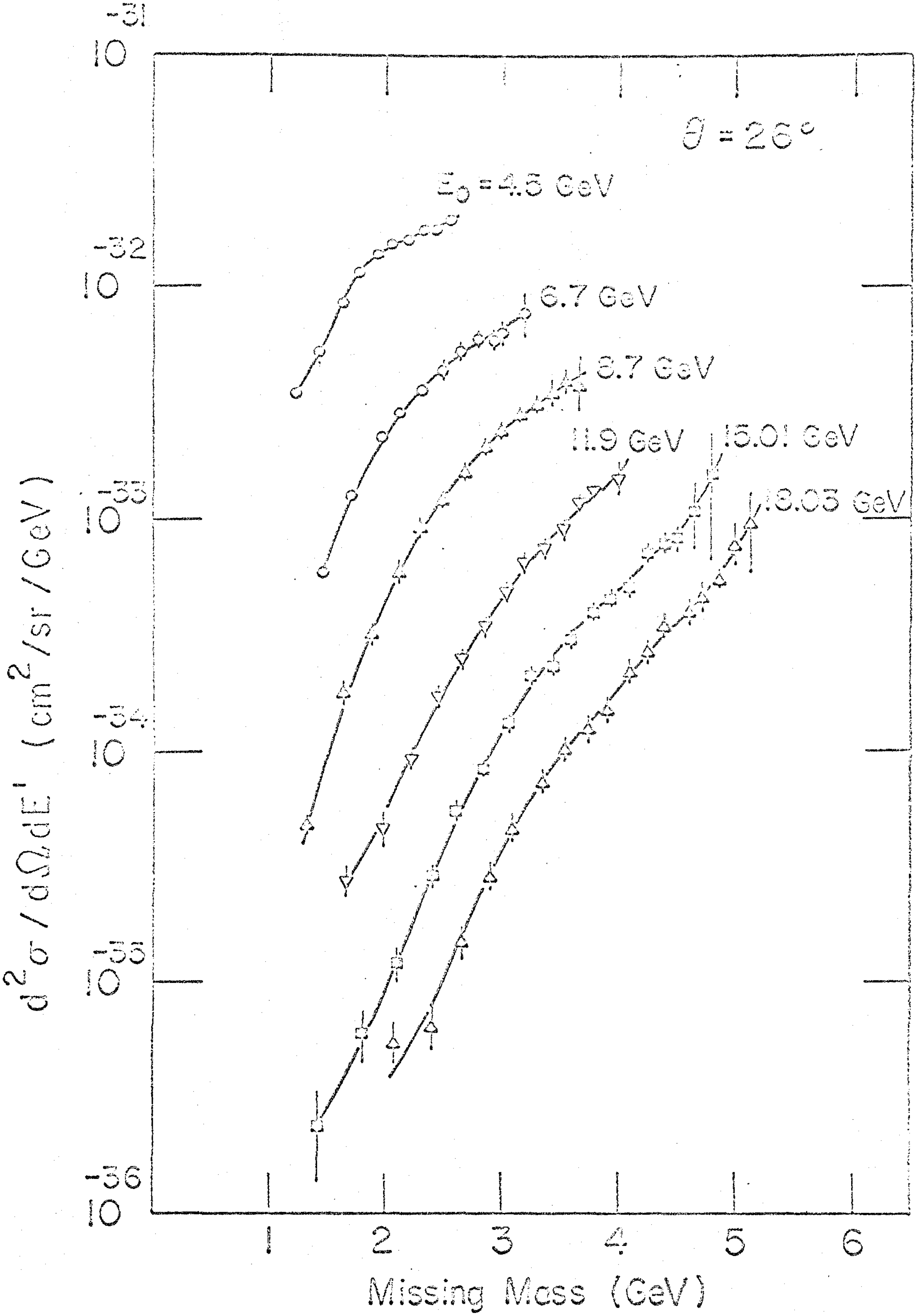
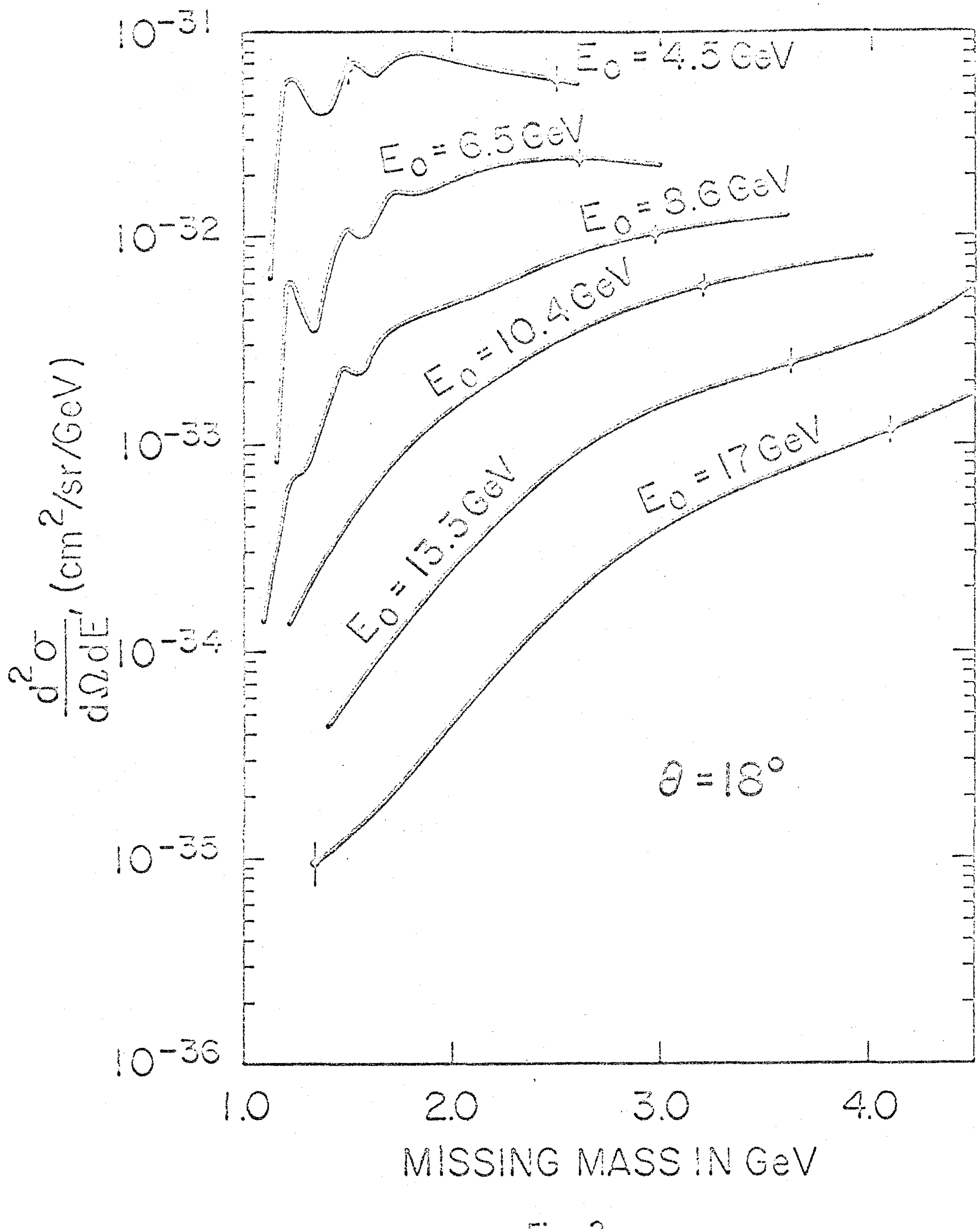

$\theta = 26°$
$E_0 = 4.5$ GeV
6.7 GeV
8.7 GeV
11.9 GeV
15.01 GeV
18.03 GeV
10^{-31}
10^{-32}
10^{-33}
10^{-34}
10^{-35}
10^{-36}
$d^2\sigma / d\Omega dE'$ $(cm^2/sr/GeV)$
1
2
3
4
5
6
Missing Mass (GeV)

Fig. 2



$E_0 = 4.5$ GeV
$E_0 = 6.5$ GeV
$E_0 = 8.6$ GeV
$E_0 = 10.4$ GeV
$E_0 = 13.5$ GeV
$E_0 = 17$ GeV
$\theta = 18°$
$\frac{d^2\sigma}{d\Omega dE'}$, (cm^2/sr/GeV)
10^{-31}
10^{-32}
10^{-33}
10^{-34}
10^{-35}
10^{-36}
1.0
2.0
3.0
4.0
MISSING MASS IN GeV

Fig. 3

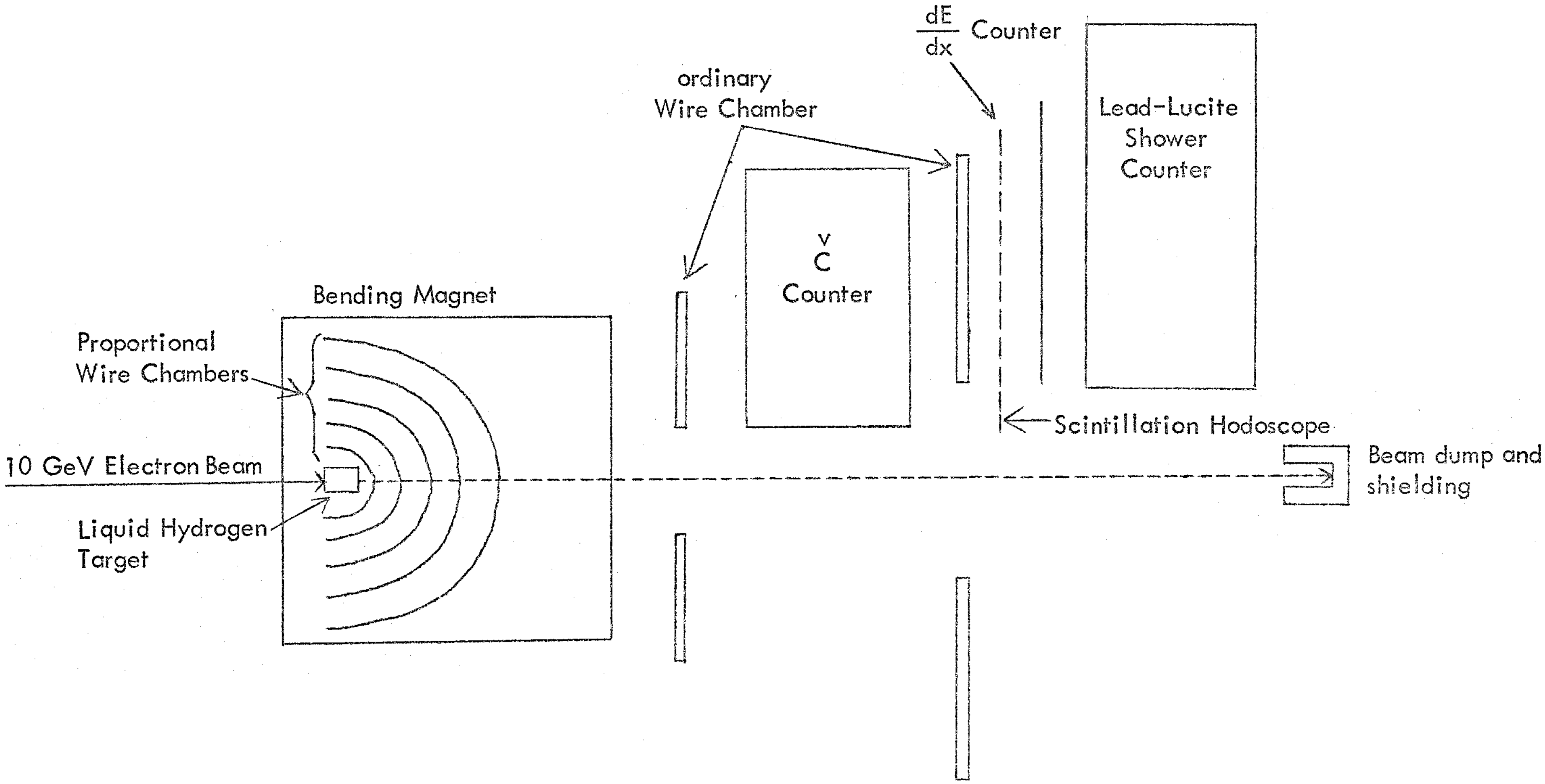
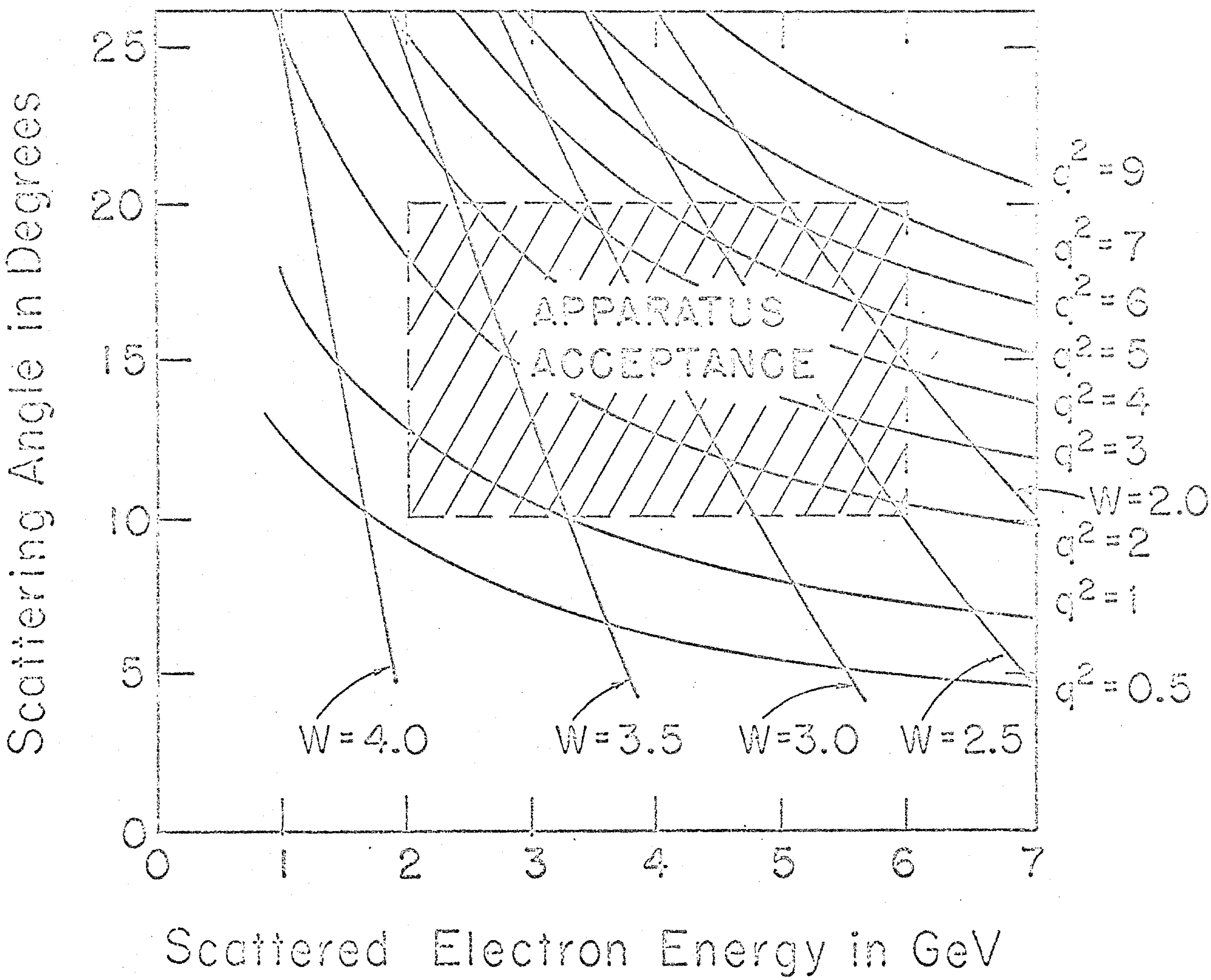
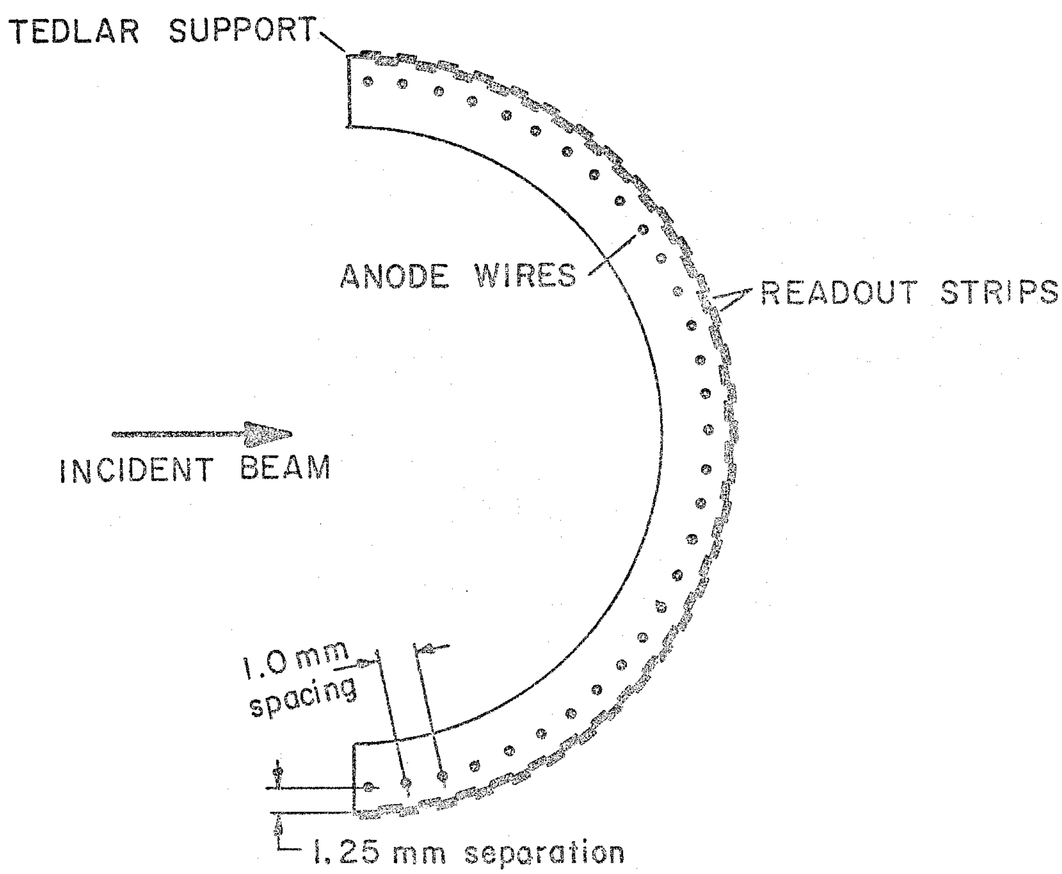


Figure 4. Schematic Diagram for the Experimental Apparatus.

Fig. 5 Kinematics for 10 GeV Incident Electrons





CYLINDRICAL PROPORTIONAL CHAMBER

Figure 6

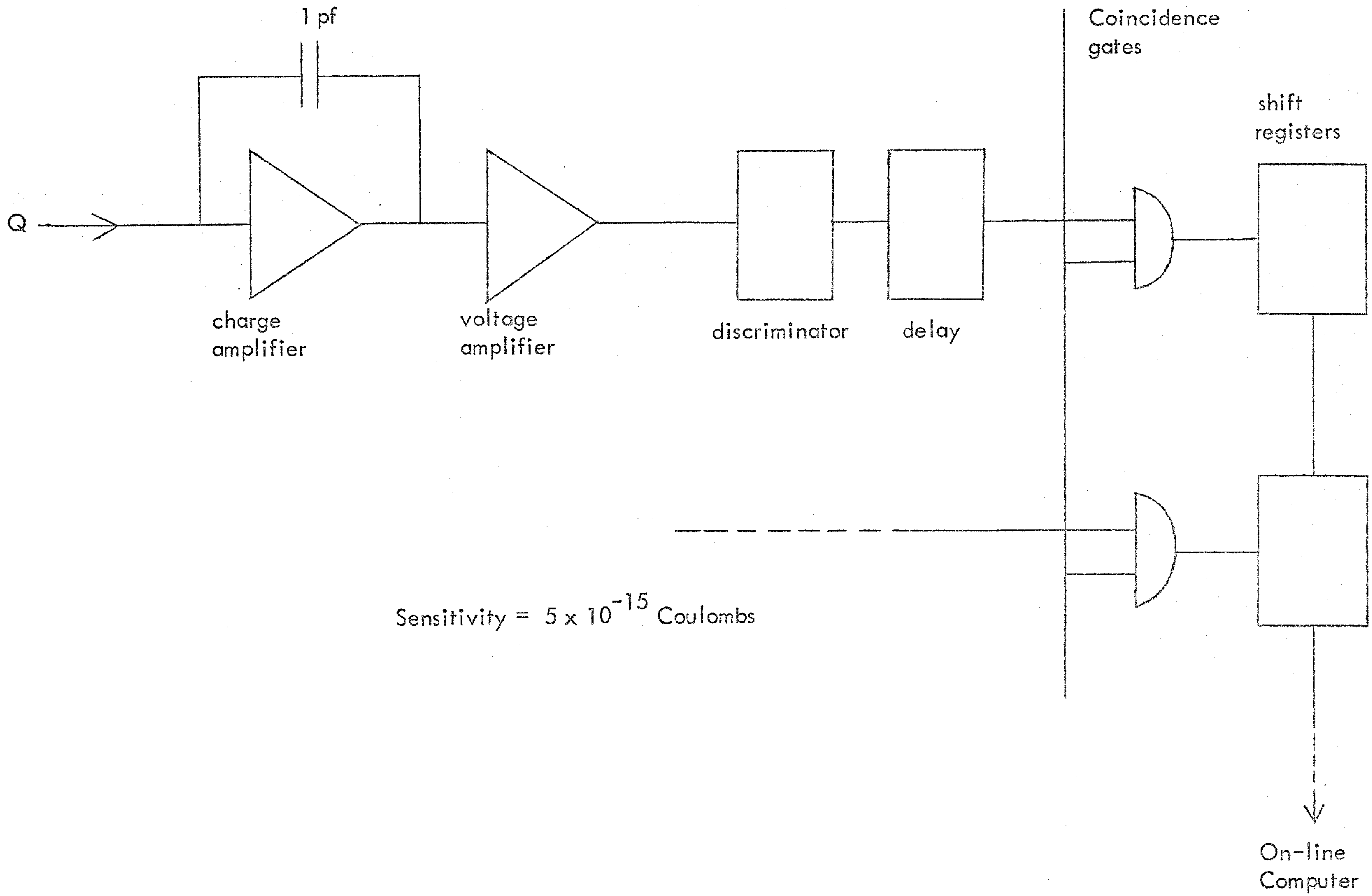


Figure 7. The charge-sensitive amplifier and read-out system.

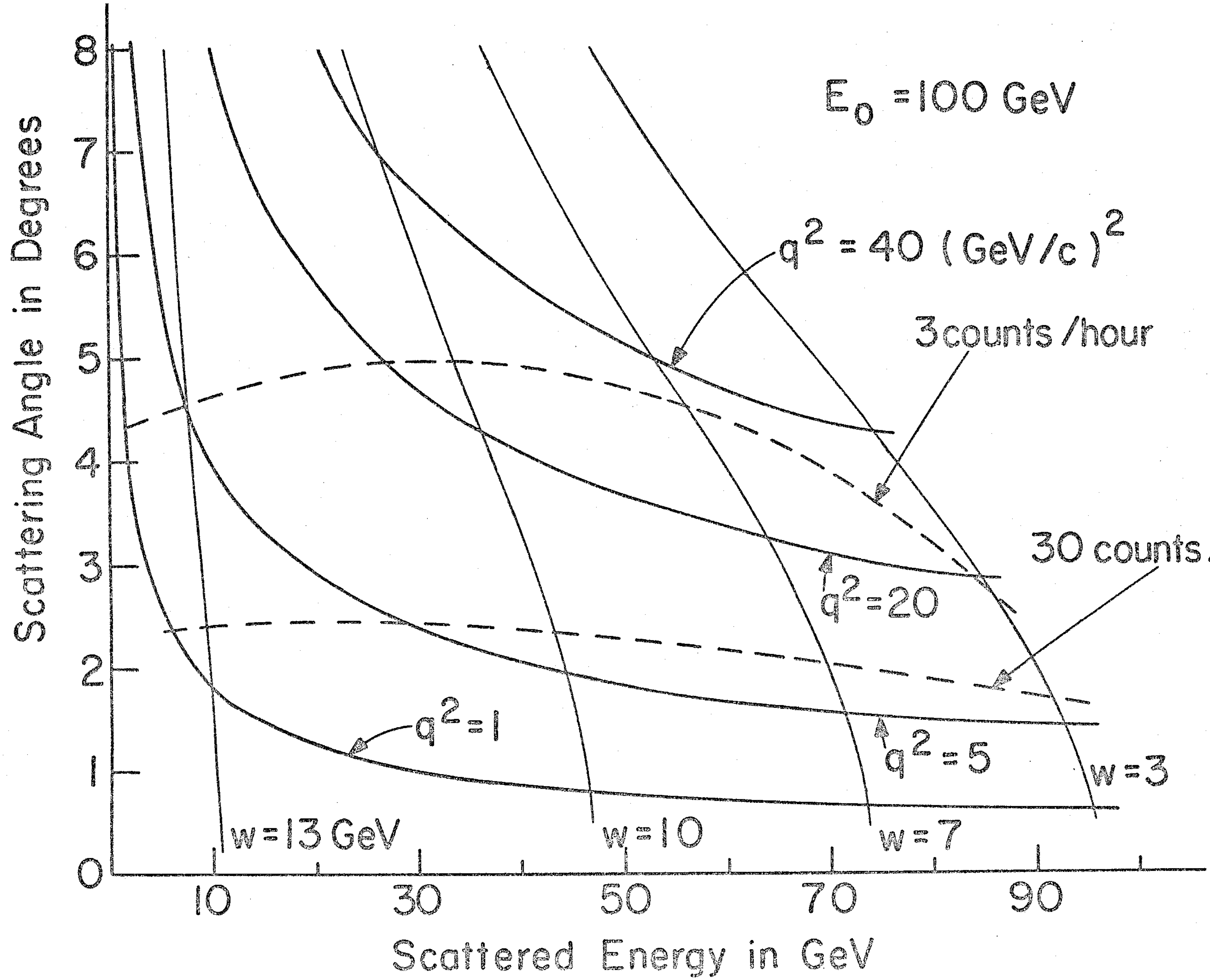

E_0 =100 GeV
q^2 = 40 (GeV/c)^2
3counts /hour
30 counts / hour
q^2=20
q^2=5
q^2=1
w=3
w=7
w=10
w=13 GeV
Scattering Angle in Degrees
Scattered Energy in GeV
0
1
2
3
4
5
6
7
8
10
30
50
70
90

Figure 8

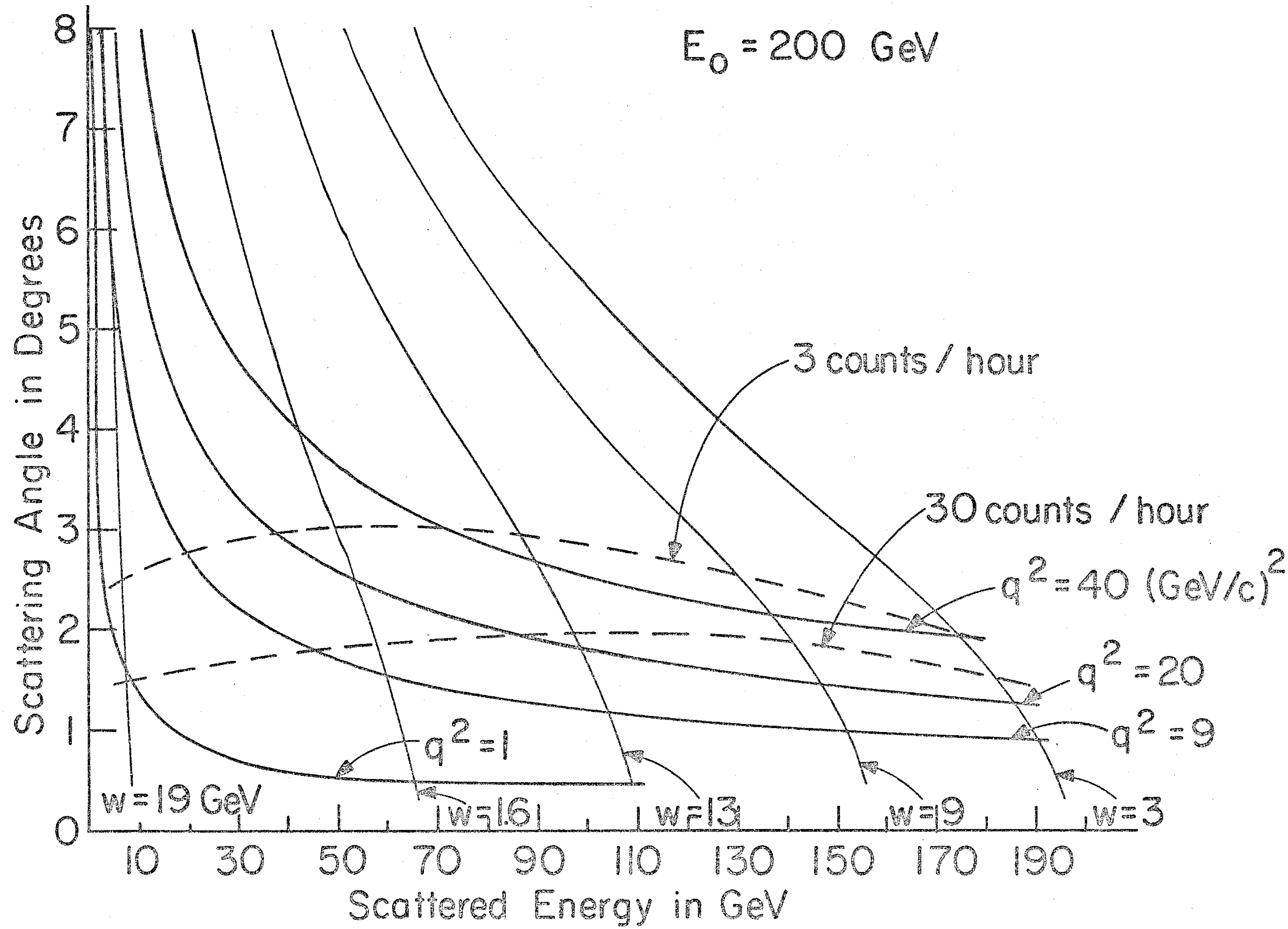

E0 = 200 GeV
3 counts / hour
30 counts / hour
q2 = 40 (GeV/c)2
q2 = 20
q2 = 9
q2 = 1
w = 19 GeV
w = 16
w = 13
w = 9
w = 3
Scattering Angle in Degrees
Scattered Energy in GeV
0
1
2
3
4
5
6
7
8
10
30
50
70
90
110
130
150
170
190

Figure 9

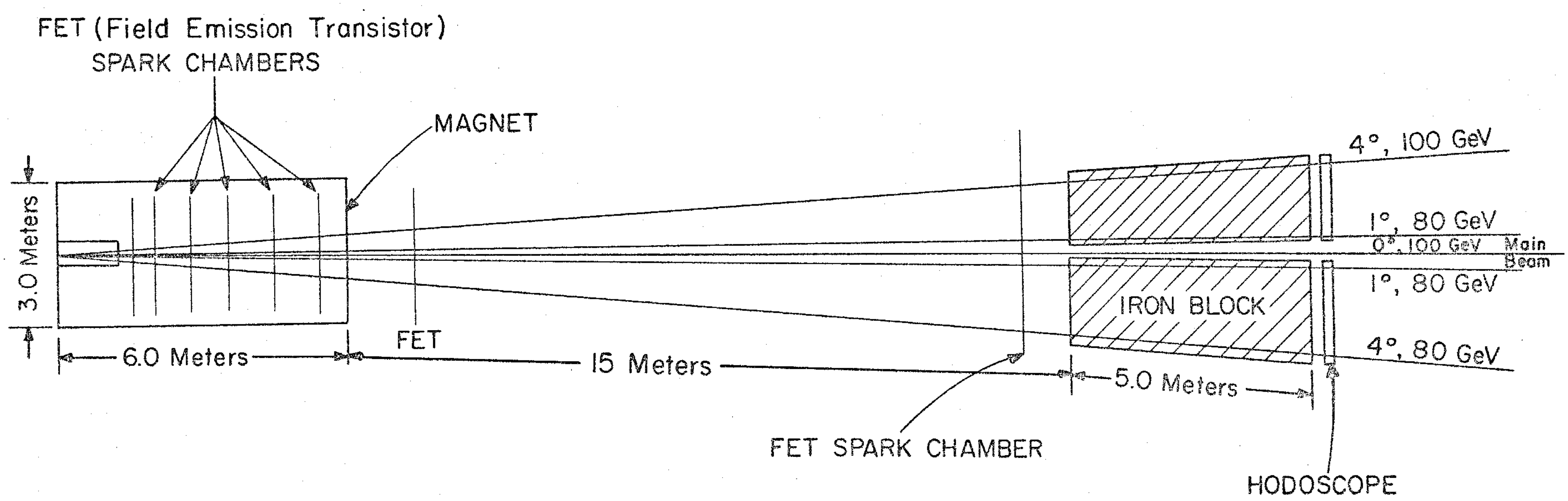


Figure 10a. Experimental Setup

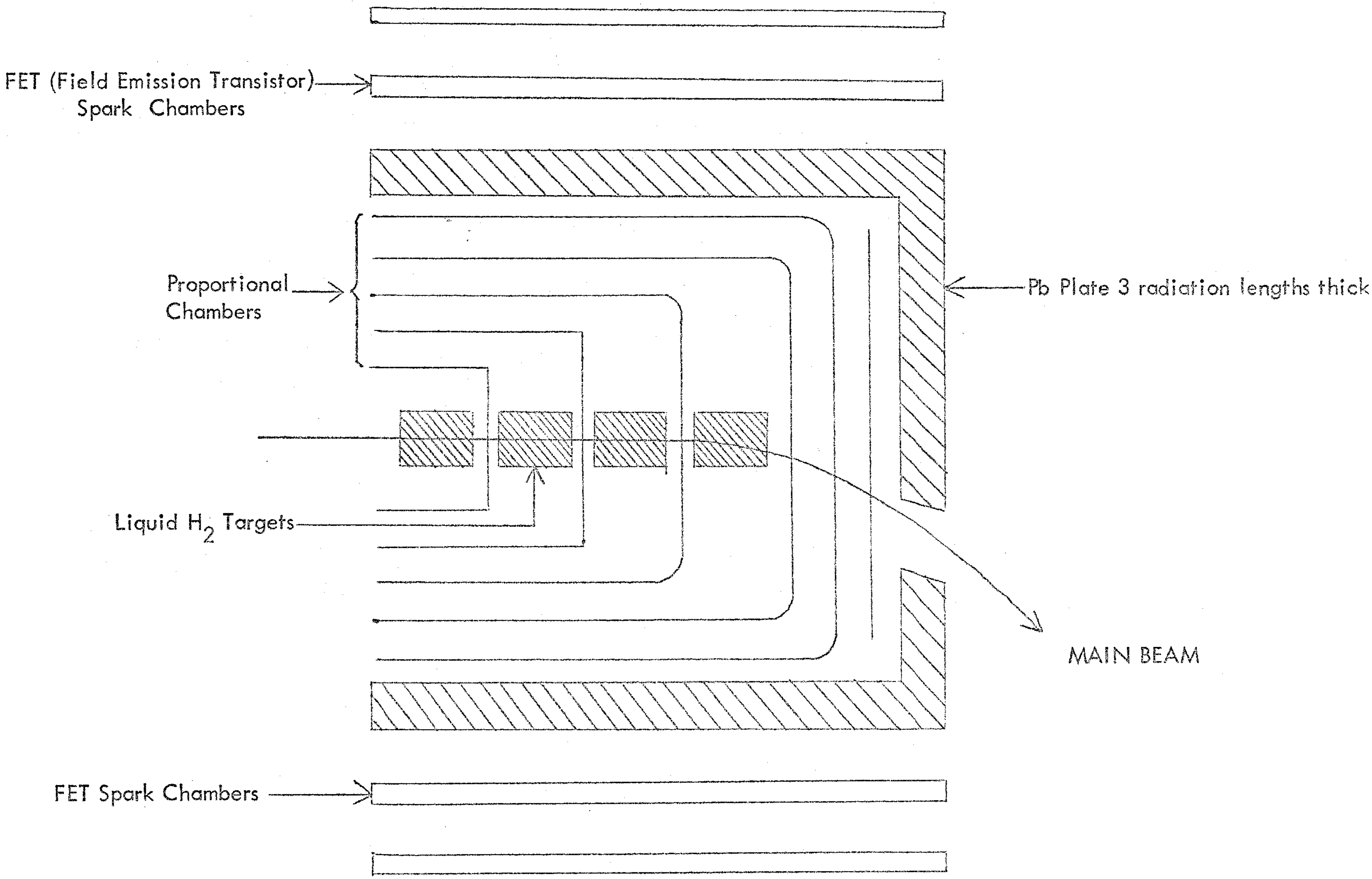


Figure 10b. Target Setup (Not to Scale)

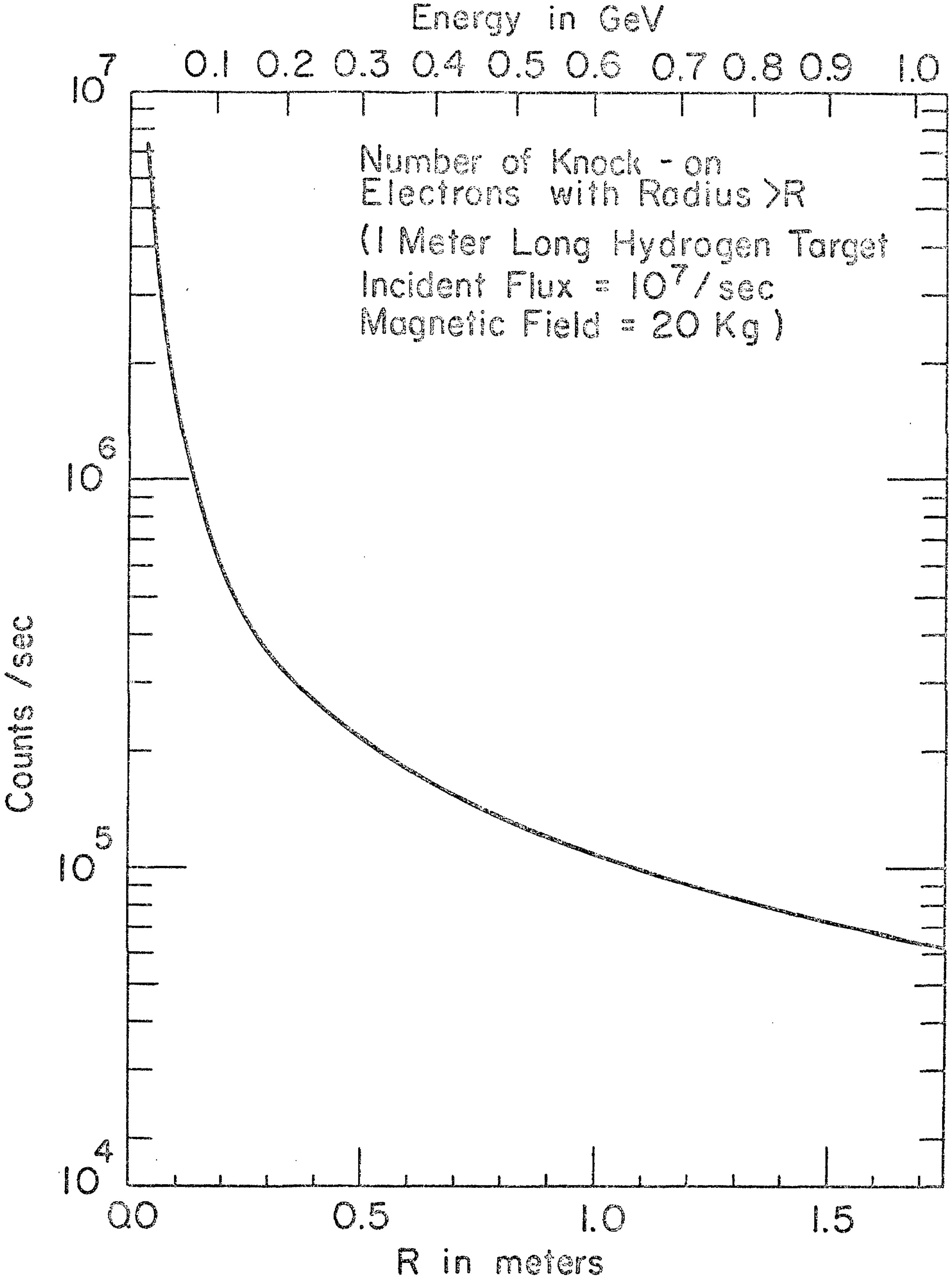

Energy in GeV
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
10^7
10^6
10^5
10^4
Counts /sec
Number of Knock - on
Electrons with Radius >R
(1 Meter Long Hydrogen Target
Incident Flux = 10^7/sec
Magnetic Field = 20 Kg)
0.0
0.5
1.0
1.5
R in meters

Figure 11.

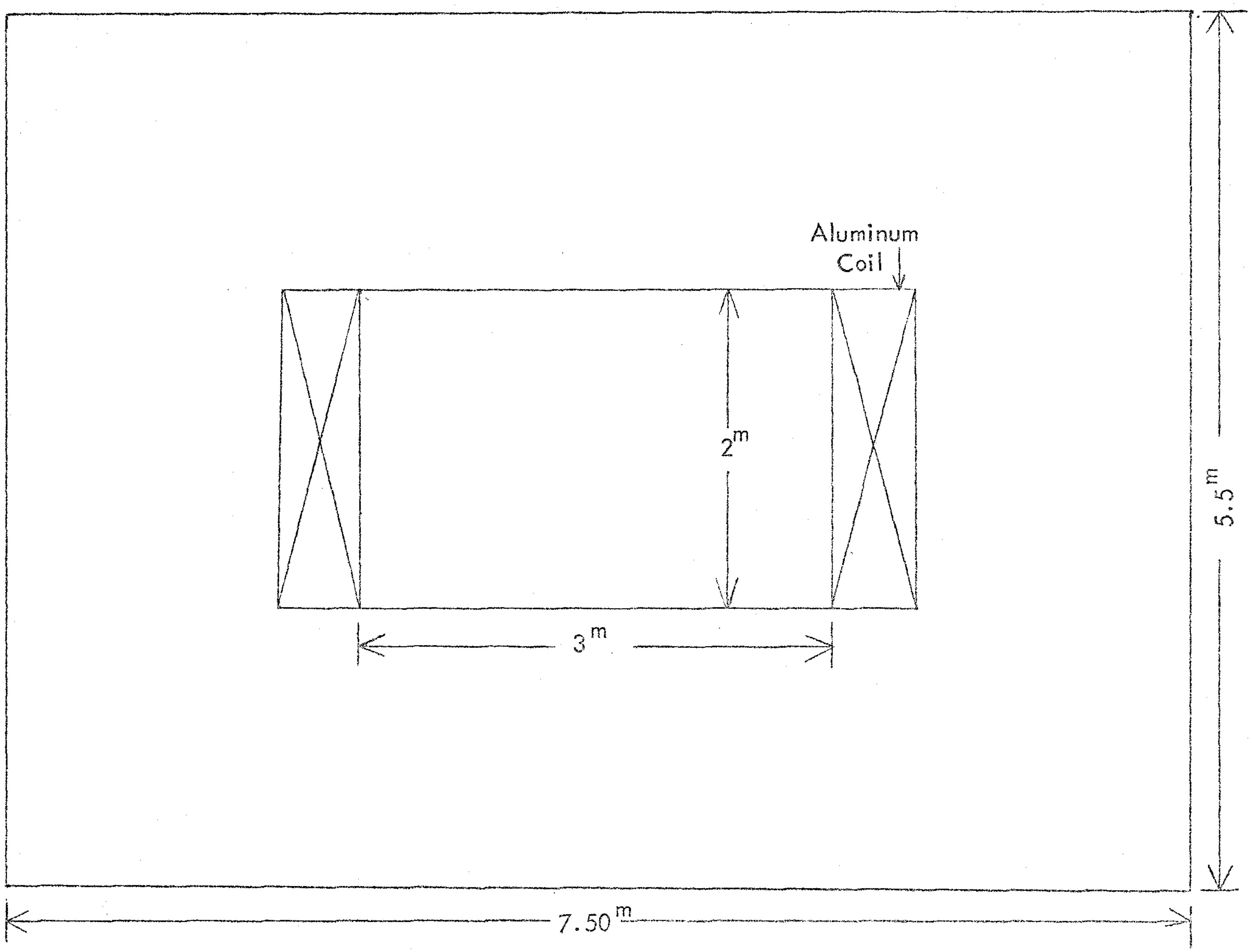


Figure 12. Cross section of the 6 meter long picture frame bending magnet.